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METROLOGY/INSPECTION POSITIONING SYSTEM

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CROSS REFERENCE TO RELATED APPLICATION

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This patent document is related to and incorporates by reference in its entirety, co-owned U.S. patent application Ser. No. 09/113,484, entitled "System using a Polar Coordinate Stage and Continuous Image Rotation to Compensate for Stage Rotation," filed July 10, 1998.

BACKGROUND

Field of the Invention

This invention relates to measurement and inspection systems and particularly to systems and methods for measuring or inspecting specific locations on a wafer while the wafer remains in a processing apparatus.

Description of Related Art

During fabrication of semiconductor devices, wafers containing devices are often inspected or measured to determine whether processes are proceeding as expected. Such measurements provide information that guides adjustments of process parameters to improve the yield of operable devices.

Typically, the inspection or measurement of a wafer requires moving the wafer to a metrology station where the wafer is mounted on a precision stage. The stage precisely positions the wafer to allow inspection or measurement of specific points on the wafer. Standalone metrology stations have drawbacks including: the space required for the station; the processing delay for removing, measuring, and returning the wafer for further processing; and possible contamination or damage to the wafer that moving the wafer introduces. Metrology equipment that measures or inspects a wafer while the wafer remains in a processing apparatus would avoid many of the drawbacks of standalone stations. However, the typical processing

apparatus lacks a stage or other means capable of precisely positioning a wafer for inspection or moving in the wafer in response to the needs of the metrology equipment. Further, the space available in and around processing apparatuses is limited so that compact equipment is required.

SUMMARY

In accordance with an aspect of the invention, a metrology/inspection system moves the optics and/or measuring equipment above a wafer or sample being inspected or measured. Thus, the metrology or inspection system permits inspection or measurement of a wafer through a window in a processing apparatus. Positioning typically requires pre-alignment to at least roughly determine the location and orientation of the wafer relative to the apparatus, and alignment which precisely identifies the position and orientation of specific features on the wafer. In accordance with an aspect of the invention, the pre-alignment uses edge detection that avoids the inaccuracy arising from pattern recognition systems. With the orientation of the wafer identified, an image rotation system presents an image of the wafer with a standard orientation. The standard orientation facilitates identification of features on the wafer, inspection of the wafer, and operation of metrology equipment to move from point to point on the wafer. More specifically, the image rotation system can maintain the standard orientation of an image of the wafer as an operator moves the optics from one inspection area to the next.

In one specific embodiment of the invention, the apparatus includes an R-θ stage that positions optics relative to the wafer. A rotation axis of the R-θ stage can either be over or outside a view area of the system. The R-θ stage provides a compact means for positioning the optics while the image rotation and control system permit a user to control motion and view the wafer using perpendicular Cartesian axes and uniform velocity linear motion.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a transparent top view of a metrology/inspection system in accordance with an embodiment of the invention.

Fig. 2 shows side view of the system of Fig. 1 when mounted on an apparatus for processing wafers.

Fig. 3 is a block diagram of a metrology/inspection system in accordance with another embodiment of the invention.

Fig. 4 shows a side views of a metrology/inspection system having a rotary stage with a rotation axis over a view window.

Use of the same reference symbols in different figures indicates similar or identical items.

DETAILED DESCRIPTION

In accordance with an aspect of the invention, a metrology/inspection system moves the optics and/or measuring equipment of the system relative to a wafer. Accordingly, measurement or inspection of the wafer does not require that the wafer be mounted on a precision stage. This allows the wafer to be at rest on any stationary structure, for example, in a processing apparatus when the system measures or inspects the wafer. In one embodiment, the metrology/inspection system examines a wafer through an optical window while the wafer sits at a cool-down station of a processing apparatus. Accordingly, measurement does not require removing the wafer from the processing apparatus and does not delay processing since the wafer can be measured, for example, during a required cool down period in device fabrication process.

Fig. 1 shows a top view of a metrology/inspection system 100 in accordance with an embodiment of the invention. System 100 includes a rotary stage 110 having a base 112 and a rotary portion 114, a linear stage 120 having a base 122 and a slide portion 124. Base 122 of linear stage 120 is mounted on rotary portion 114 of rotary stage 110. A case 130, which contains measuring devices and an imaging system including an objective 140, is mounted on slide

portion 124 of linear stage 120. The combined movement of stages 110 and 120 can move objective 140 radially towards and away from a rotation axis 116 and rotate objective 140 about axis 116. Rotary and linear stages 110 and 120 position objective 140 over a wafer for measurement or inspection of specific areas or features on the wafer. Rotary and linear stages with suitable precision are currently available from a variety of commercial sources and are commonly used to position wafers for processing. Commercially available R-θ stages can also accomplish the described movement of objective 140.

The location of objective 140, which is, for example, an objective lens of an optical system, establishes a measurement point or inspection area for the imaging system and measurement devices in case 130. Movement of slide portion 124 moves objective 140 along a linear axis R. The range of motion of linear stage includes a minimum radius Rmin and a maximum radius Rmax, where the difference between Rmax and Rmin is greater than the diameter of a wafer or other sample 150 by more than the expected error in the placement of sample 150 for viewing. Rotation of rotary portion 114 swings objective 140 along an arc and changes the orientation of axis R of linear stage 120. The angular range of motion of rotary stage 110 is greater than twice the largest angle θm that a radius of sample 150 spans relative to a rotation axis 116 of rotary stage 110. Larger ranges of motion permit positioning of system 100 so that case 130 does not block the view of sample 150. Generally, polar coordinates r and θ associated with the orientations of stages 110 and 120 identify the location of objective 140.

In an exemplary embodiment of the invention, objective 140 is the objective lens of a reflected-light microscope. Typically, a video camera records the image from the microscope for image processing and/or display on a monitor (not shown). An operator of system 100 uses the displayed image when inspecting the wafer or controlling movement for measurements at selected points on sample 150. Measurement devices can tap and analyze part of the light from an optical imaging system including objective 140, or the measurement devices can use their own sensors or optics. For example, a mirror in the optical path from objective

140 can direct light to a spectrometer. The spectrometer measures the spectrum of light reflect from the wafer to identify constructive or destructive interference and identify the thickness of films on sample 150. Further, the optical system may include other devices such as an OCR system or a bar-code reader that can read markings on sample 150.

As described further below, an optical or electronic image rotation system rotates the image from the imaging system as required to present an image of a portion of sample 150, with a standard orientation. One standard orientation, for example, has a flat 155 on sample 150 toward the bottom of the image, but any orientation of sample 150 can be picked as the standard orientation. Having a standard orientation simplifies identification of particular points or areas on the wafer for viewing by objective 140.

Fig. 2 shows a side view of the system 100 when base 112 of rotary stage 110 is mounted on a processing apparatus 200. Processing apparatus 200 may for example be a CVD (chemical vapor deposition) chamber or PVD (physical vapor deposition) chamber. Apparatus 200 includes a station 230 such as a cool down station where sample 150 rests. An optical window 220 is located above station 230 or otherwise position to permit viewing of sample 150 through optical window 220. Generally, processing equipment includes view window which can be replaced with optical grade window for use with measurement systems in accordance with embodiments of the present invention.

In one exemplary embodiment of system 100, stages 110 and 120 are portions of a polar stage from Kensington Laboratories. The stage moves objective 140 in a range between +105 mm to -105 mm from rotation axis 116, and the angular movement of objective 140 up to 180 degrees. This permits inspection of wafers up to 200 mm in diameter. A great variety of other stages can be used for viewing of samples of various sizes. Additionally, a z coordinate stage can be added to or integrated into stages 110 and 120 for focusing of the imaging system. For example, case 130 which encloses at least portions of the imaging system can attach to the z coordinate stage for focusing on sample 150.

FIG. 3 illustrates a metrology/inspection system 300 in accordance with another embodiment of the invention. System 300 includes an operator interface 310, a control system 320, an imaging system 330, and a polar coordinate stage 340. Polar coordinate stage 340 can be a standard polar coordinate stage such as commercially available from a variety of sources. Alternatively, polar coordinate stage 340 is a combination of rotary and linear stages such as described above. Polar coordinate stage 340 changes the view point of the objective 140 of imaging system 330 by rotating imaging system 330 about a rotation axis or by linear movement that changes a radial distance r from the rotation axis of stage 340 to objective 140. A rotary encoder monitors the angular orientation θ of the radial axis relative to a reference direction. The radial axis is along the linear drive direction and is also referred to herein as the R coordinate axis. A linear encoder monitors the linear position of objective 140 along the R coordinate axis.

Operator interface 310 and control system 320 can be implemented in a computer system that includes appropriate hardware and software for the tasks described herein. For example, operator interface 310 includes a video monitor 314 that displays an image of an inspection area on a wafer 350 and an operator control 312 that allows the operator to select the inspected area.

Imaging system 330 is for inspecting regions of wafer 350. In system 300, imaging system 330 includes a visible or UV reflected-light microscope, a video camera 332, an apertured mirror 334, and a spectrometer 338. In operation, a light source (not shown) illuminates a portion of wafer 350, and some light reflected from wafer 350 enters objective 140. Mirror 334 reflects a portion of the light from objective 140 to video camera 332 and passes a portion of the light from objective 140 to spectrometer 338. Camera 332 generates a signal representing the image that a monitor 314 displays. Objective lens 140, mirror 334, and camera 332 are merely illustrative of typical optical elements. Generally, additional optical elements are required to achieve the desired field of view and magnification of a suitable imaging system 330. In one embodiment, imaging system 330 includes a confocal microscope.

Spectrometer 338 is an example of a measurement subsystem associated with imaging system 330 for measurement of particular properties at points on wafer 350. Spectrometer 338 measures the spectrum of the light reflected from wafer 350 and from the relative reflectance of different wavelengths, can identify wavelengths particularly subject to constructive or destructive interference upon reflection from wafer 350. Control system 320 can identify film thicknesses from the spectrum that spectrometer 338 measures. Imaging system 330 can additionally or alternatively include other measurement subsystems such as an interferometer, a reflectometer, an ellipsometer, an FTIR spectrometer, or any other type of spectrophotometer. Spectrometer 338 and other measurement subsystems can measure wafer 350 through other elements (e.g., objective 140) of imaging system 330 or operate independently to measure a point or points in or near the field of view of imaging system 330.

Video camera 332 forms an image of a region of wafer 350 and sends a signal representing the image to control system 320. The orientation of the image depends on the orientation of wafer 350 and the orientation of imaging system 330. Accordingly, if the images from video camera 332 were directly displayed on monitor 314, matching areas of different wafers 350 would be displayed with random orientations that depend on the orientations of the wafers. Such variations in the orientations of images would make the task of inspecting wafers more difficult. Further, when moving from one inspection area to another on wafer 350, the images would rotate as imaging system 330 rotates. Such image rotations make operator control of movement difficult. To avoid these problems, control system 320 includes an electronic image rotation unit 328 that rotates the image from video camera 332 by an angle selected according to the orientations of wafer 350 and imaging system 330.

Optionally, imaging system 330 may include active image rotation optics that provide an adjustable rotation of the image to cancel image rotation that stage 340 causes when moving optical system 330 or to correct for variation in the orientations of wafers 350 being examined. In an exemplary embodiment of the

invention, image rotation optics includes, for example, a motor driven dove prism. Dove prisms are well known optical elements that provide image rotation about an optic axis, in this case the optical axis of imaging system 330. In an embodiment including active image rotation optics, control system 320 generates a signal that controls the optical image rotation. For example, the optical system can rotate the image at a rate that compensates for rotation or movement of imaging system 330.

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~~In an exemplary embodiment, imaging system 330 includes an optical microscope that provides a field of view at wafer 350 which is about 1.3 mm x 1 mm. An aperture in mirror 334 passes light from a small spot (about 15 microns in diameter) at the center of the field of view of objective 140 to spectrometer 338 which collects data on the reflectance. This data can be used for determining the film thickness. U.S. patent App. entitled "Compact Optical Reflectometer System," of R. Yarussi and Blaine R. Spady, Ser. No. 09/347,362, Attorney docket no. 7556-0001, describes some suitable measuring and imaging systems and is hereby incorporated by reference in its entirety.~~

As mentioned above, operator interface 310 enables observation of an inspection area of wafer 350 and selection of the inspection area. Operator interface 310 includes monitor 314 and operator control 312. Monitor 314 is a conventional video monitor capable of displaying an image represented by a signal from video camera 332. In particular, monitor 314 displays the image of the inspection area of wafer 350, and an operator uses operator control 312 to change the inspection area. Specifically, operator control 312 is for input of movement commands and directing the motion of objective 140. In an exemplary embodiment of the invention, operator control 312 is a mouse or keyboard that inputs commands to software in control system 320. Alternatively, operator control 312 can be a joystick, a touch sensitive screen, a track ball, a touch pad, or another pointing device. In the exemplary embodiment, an operator, observing the image from camera 332 on monitor 314, can use operator control 312 to select the direction and speed of linear motion of the field of view relative to the displayed image. The operator can also select automatic movement to preselected areas on

wafer 350 or movement that follows features appearing in the image displayed on monitor 314.

Operators observing image motion on monitor 314 typically expect linear motion. Accordingly, control system 320 generates commands to polar coordinate stage 340 that cause linear motion of objective 140 relative to wafer 350. Additionally, to maintain the orientation of the displayed image, control system 320 changes the amount that image rotation unit 328 rotates the image from camera 332.

In an exemplary embodiment, control system 320 is a computer such as a 600 MHz Pentium II-based personal computer having a video capture board for connection to video camera 332 and interfaces 324 and 326 for connection to stage 340. Video capture boards capable of performing real time image rotation required of image rotation unit 328 are commercially available from a variety of sources. The interface board required for connecting to stage 340 depends on the type and manufacturer of stage 340.

In control system 320, a software command module 322 interprets the signals from operator control 312 and directs hardware control units 324 and 326 to generate signals for controlling stage 340 and image rotation unit 328. In particular, command module 322 includes software that control system 320 executes to monitor and control r and θ coordinates of stage 340 and control the angle through which image rotation unit 328 rotates the image. Control system 320 thus determines and applies signals to an angle control unit 324 and a radius control unit 326 so that stage 340 moves imaging system 330 at the desired speed in the desired direction. In the exemplary embodiment, control units 324 and 326 combined include a hardware interface conveying information to and from stage 340. Known computer controlled polar stages and their interfaces are suitable for system 300.

As stage 340 moves imaging system 330, command module 322 commands image rotation unit 354 to rotate the image. The image rotation has the same direction and rate as the rotation of imaging system 330 so that the orientations of

features appearing in the image remain fixed on monitor 314. For example, when the operator directs movement of the image along a feature that initially appears horizontal on monitor 314, control system 320 generates and applies a control signal to image rotation unit 328 to compensate for stage 340 rotating imaging system 330, and the feature in the image remains horizontal as the image moves.

In an exemplary embodiment of the invention, image rotation unit 328 includes an acquisition board that receives a video image signal from camera 332 and a module from rotating the video image. In the exemplary, embodiment the video image rotating module is a VigraVision PCI card from Visacomm, Inc., but alternatively, the module can be implemented in software. When command module 322 directs stage 340 to rotate wafer 350, the image from camera 332 is of a rotating (and moving) portion of wafer 350. Image rotation unit 328 processes the input video signal to compensate for the rotation and generates an output video signal representing a moving image which preserves the orientations of features on wafer 350. Control system 320 then provides a video signal representing the corrected image to video monitor 314.

Before an operator uses system 300 to measure or inspect wafer 350, command module 322 directs pre-alignment and alignment processes to accurately determine the position and orientation of wafer 350. Typically, a sample such as a wafer placed at a station in a processing apparatus has a position that is known to an accuracy of one to several millimeters, and angular orientation of the wafer may be completely random or unknown. In accordance with an aspect of the invention, a pre-alignment procedure determines the position and orientation of wafer 350 by detecting the edge and an alignment feature (e.g., a notch or flat) on the edge of wafer 350.

For pre-alignment of a wafer 350, command module 322 directs stage 340 to move objective 140 until an edge of wafer 350 is detected. An edge can be identified using video camera 332 or using spectrometer 338. Edge detection using video camera 332 employs image recognition software that identifies an edge from contrast in the image. Spectrometer 338 detects the edge as a drop in the measured

reflectance for most or all wavelength as objective 140 passes an edge of wafer 350. Other resources in the optical system such as a reflectometer or other device that measures the intensity of reflected light could similarly detect the edge from a drop in reflected light. Alternatively, the pre-alignment process can use a separate edge detection system. Detecting three or four points on the edge of wafer 350 is sufficient for identification of the position of wafer. Using edge detection and particularly using spectrometer 338 avoids the difficulties the conventional image recognition software has when attempting to identify a structure on a wafer having a completely unknown alignment. After identifying a point on the edge of wafer 350, command module 322 then directs stage 340 to move objective 140 along the edge of wafer 350 for detection of an alignment feature such as a notch or flat that indicates the orientation of wafer 350. Once the notch or flat is found, the position and orientation of the wafer are known. However, the pre-alignment determination of position and orientation may not be sufficient for many applications. In particular, inspection and measurements of a wafer are typically of features formed on the wafer, and such features may not have a completely consistent position relative to the edge of wafer 350.

The next level of alignment is a deskew procedure. The deskew procedure can be done with video camera 332 and an image recognition module that identifies a feature such as an alignment mark in the field of view of video camera 332. In particular, if the pre-alignment procedure aligns features on wafer 350 within a variance of approximately 0.2 mm, centering a 1 mm x 1 mm field of view of camera 332 on the expected location of the desired feature will include the feature in the image. Image recognition software executed in control system 320 can then find the position of the feature to within a few microns. Repeating the alignment process with a feature in another location on wafer 350 can accurately find the position and orientation of features on wafer 350. If stage 340 is accurate enough, system 300 can find any point on wafer 350 within a few microns simply by controlling the settings of stage 340. If stage 340 is not sufficiently accurate, the pattern recognition is repeated at subsequent measurement points for fine

adjustments at or near measurement points. When the position and orientation of wafer have been accurately identified, inspection or measurement of wafer 350 can be performed.

Fig. 4 illustrates a metrology/inspection system 400 in accordance with another embodiment of the invention. System 400 includes a rotary stage 410 and a linear stage 420 that are mounted on a support structure 415, above an optical window 220. A rotation axis 416 of rotary stage 410 intersects and may be centered on optical window 220. Imaging system 130 is on linear stage 410, and the combined motion of rotary stage 410 and linear stage 420 can position objective 140 over any point on a wafer 350 that may have an arbitrary orientation on station 230. System 400 has the advantage of being compact when compared to a similar system that has imaging system 130 on an X-Y stage.

Although the invention has been described with reference to particular embodiments, the description is only an example of the invention's application and should not be taken as a limitation. Various adaptations and combinations of features of the embodiments disclosed are within the scope of the invention as defined by the following claims.